spotlights

How We Survived the Big Bang

The fact that we exist in a universe dominated by matter is a cosmic mystery. Because antimatter annihilates matter, these words you are reading, the clothes on your body, and your body itself are all evidence of there being more matter than antimatter in the universe. Los Alamos experimental nuclear physicist Takeyasu Ito and nuclear theorist Vincenzo Cirigliano want to know how this imbalance could have come about, so they and their teams of experts are working together to learn more.

For every particle, there exists a corresponding antiparticle: protons and antiprotons, electrons and antielectrons, quarks and antiquarks, and so on. The broadly accepted Standard Model of particle physics, which describes all the elementary particles and their interactions, implies that interchanging particles and antiparticles (which have the same mass but opposite charge), in an operation called charge-parity (CP) is, to a very high degree of accuracy, a symmetry of nature. The small amount of asymmetry, or CP violation, that *is* allowed by the Standard Model is not enough to explain the imbalance.

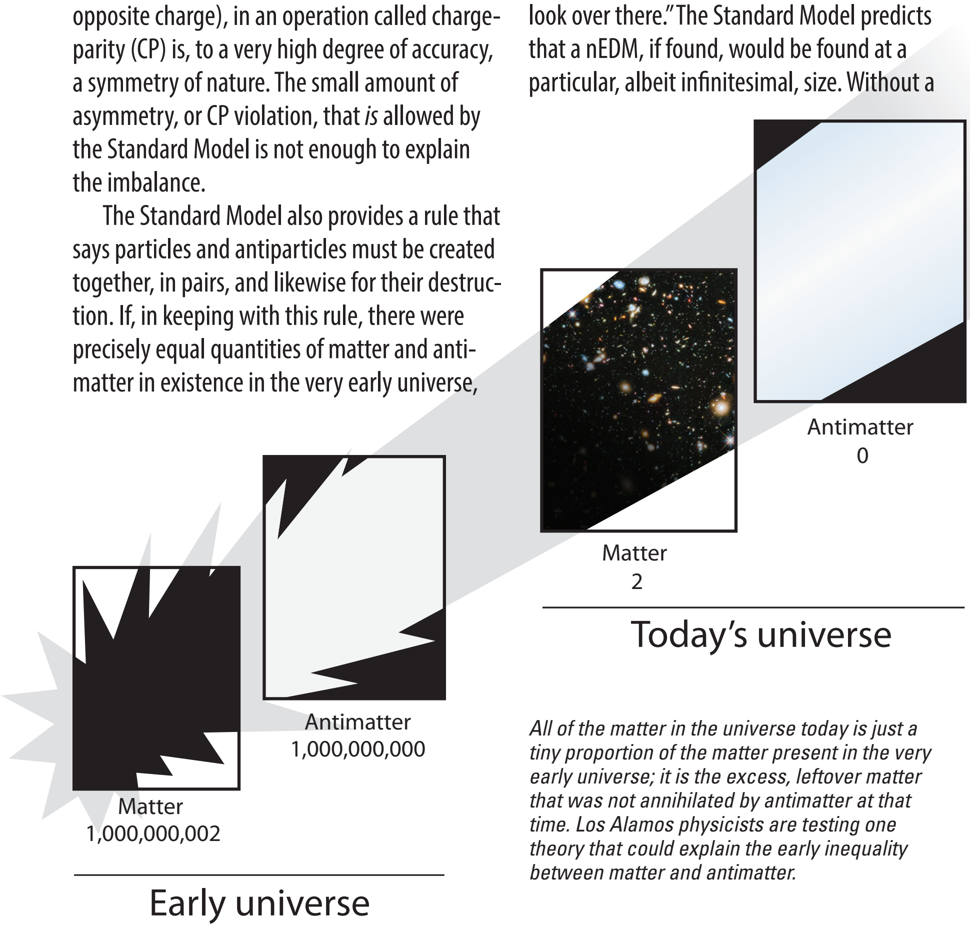
The Standard Model also provides a rule that says particles and antiparticles must be created together, in pairs, and likewise for their destruction. If, in keeping with this rule, there were precisely equal quantities of matter and antimatter in existence in the very early universe, they would have exactly canceled each other, or mutually annihilated one another, and there would have been no matter left over. So amidst the maelstrom of the very early universe, CP violation allowed the survival of enough matter to form galaxies, planets, people, and every other tangible thing. But it's not obvious why CP violation exists in the first place.

"If a neutron were enlarged to the size of the earth, there would be less than a tenth of the diameter of a human hair's separation between the centers of negative and positive charge within it," Ito explains. This is the elusive, still theoretical, neutron electric dipole moment (nEDM), which, if proven to exist, would signal CP violation at levels much higher than those predicted by the Standard Model, and maybe enough to solve the mystery. When searching for such a small thing, scientists can rarely say, "It's right here"; more often, they say, "It's definitely not here, here, or here, so let's look over there." The Standard Model predicts that a nEDM, if found, would be found at a particular, albeit infinitesimal, size. Without a way to look exactly where the model predicts, scientists must narrow in on it, exploring a range of numbers around the predicted one. Presently the upper limit of that range remains five to six orders of magnitude larger than the size predicted by the Standard Model. Now Ito and Cirigliano, along with many collaborators, are poised to shave one or even two orders of magnitude off.

A neutron is like a magnetized spinning top with electric and magnetic poles aligned. Imagine a gyroscope spinning about its internal axis of rotation *and* swiveling in a very smooth sort of wobble, around the center of the stand on which it is balanced. A neutron behaves similarly, spinning about a central axis and rotating around such that the orientation of the axis oscillates. The oscillation is called precession, and the rate of precession, or how long the gyroscope takes to make one revolution about its stand, is what Ito is measuring.

For the past 60 years, scientists have been looking for the nEDM in essentially the same way: Place slow neutrons in an electric field and measure their rate of precession. The difference, if there is one, in precession rate for parallel and antiparallel fields reflects the nEDM. But it's slow going. Increasing the strength of the electric field, the number of neutrons, or the time to decay can improve the sensitivity of this method. Ito and the experimental team are developing a new experiment with an increased number of neutrons, which is enabled by the ultracold neutron source at Los Alamos (one of only a few in the world). At the same time, as part of a large international collaboration, they are working on an experiment based on a completely new method involving liquid helium that is expected to raise all three variables simultaneously. So far they have shown that they can increase the electric field strength and the time to decay.

As if that weren't tricky enough, there's another hitch. Far enough back in time, the very early universe contained no neutrons; it was too hot and dense. Instead it contained quarks (and antiquarks). Since quarks are the particles that make up matter (including neutrons), a disparity early on could be the answer to the current preponderance of matter. Measuring



All of the matter in the universe today is just a tiny proportion of the matter present in the very early universe; it is the excess, leftover matter that was not annihilated by antimatter at that time. Los Alamos physicists are testing one theory that could explain the early inequality between matter and antimatter.

neutrons in the laboratory today, however, and extrapolating implications for quarks (and antiquarks) 13.8 billion years ago requires quite a bit of theoretical calculation. Cirigliano and the theory team are performing the intricate calculations needed to interpret either a positive or null experimental result in terms of quark-level sources of CP violation. No matter what the number is when it's finally measured, they want to know what it means.

The benefit of experimentalists, like Ito's team, and theorists, like Cirigliano's team, working together on these types of problems is that they whittle down and refine the scope of each other's work. The team has its short-term endeavor as well as the longer-term international collaborative experiment—which will be installed at the Spallation Neutron Source facility at Oak Ridge National Laboratory—both aimed at homing in on the nEDM. If they are successful in either or both, a popular family of theories referred to as supersymmetry, designed to address the deficiencies in the Standard Model, could be largely invalidated.

"We are agnostic when it comes to supersymmetry," says Cirigliano. "It could be right or it could be wrong. If it's right, and the nEDM doesn't exist, we'll just have to come up with a new explanation." They aren't pursuing a specific agenda after all; they are just studying new interactions beyond the known ones, beyond the Standard Model. LDRD

—Eleanor Hutterer

Safety in Numbers

After 18 years of development, the Los Alamos advanced encryption technology QKarD (a smart card based on Quantum Key Distribution) is headed to market. In the largest information technology agreement ever signed by the Laboratory, the startup company Whitewood Encryption Systems, Inc., aims to use the patented technology to develop a commercial device for creating completely secure electronic communications.

Anyone who has ever had a credit card number stolen online, or worse, a complete identity stolen, will know just how important it is that companies keep their customers' data secure. Conventional encryption methods are not perfect and rely on the difficulty—not impossibility—of cracking a code to steal information. QKarD meanwhile uses an encryption system that is both rapid and completely secure, even against future methods of cracking. One of the key innovations that enables this is the ability to produce truly random numbers—an essential component of secure encryption. There are many prominent examples of codes being cracked due to imperfect random number generation; e.g., Sony's master key for authorizing software on Playstation 3 was stolen in 2010, and the Bitcoin implementation on Android devices allowed Bitcoins to be stolen in 2013.

Encryption is the process of encoding information such that only individuals who possess the same secret numerical "key" may unlock the message. This process is fundamentally simple: Information is encrypted by carrying out a mathematical operation on it in combination with the key. For instance, the operation could be multiplication by the key. Say the message to be communicated is 7 and the key is 3; then the encoded message would be 21. In order to decipher the information, the recipient would reverse the operation using the secret key—they would divide 21 by 3 to get the message 7. Of course, in reality, the message is rarely as simple as 7, and the encryption operation is much more sophisticated than multiplication, but the principle is the same: without the key (and knowledge of the operation), the information remains encrypted.

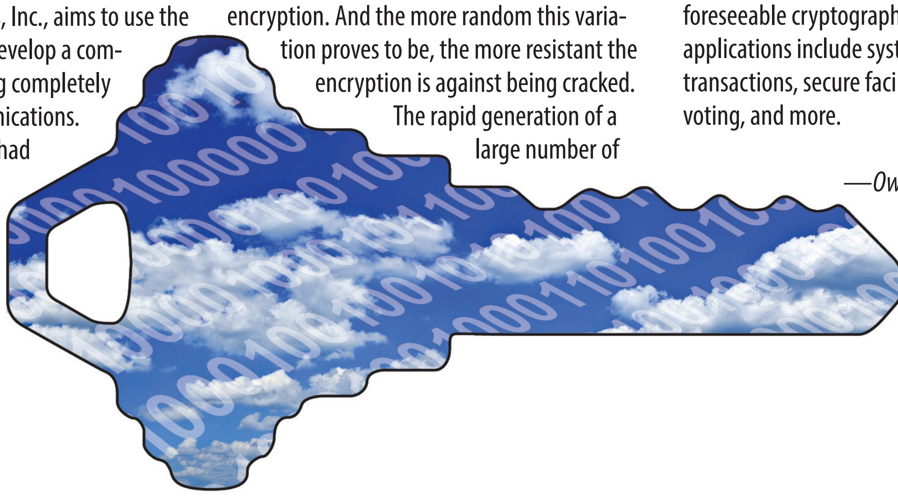
But how does one choose the value of the key? This is where random numbers come in. If an identical message, such as an individual's checking account number, is repeatedly encrypted with the same secret key, the encrypted output would be the same every time, so it is essential to vary the key with each encryption. And the more random this variation proves to be, the more resistant the encryption is against being cracked.

The rapid generation of a large number of keys is important for commercial or security applications in which a large number of secure transmissions is processed daily. Machine-generated random numbers used for encryption keys are typically either derived from physical phenomena, such as microscopic electrical sources of white noise, or from a so-called pseudo-random algorithm: a complex mathematical formula that generates numerical sequences that appear random to anyone who doesn't know the formula's inputs. The former method is slow to generate a large quantity of random numbers and is susceptible to manipulation at the source of the noise, whereas the latter is vulnerable to mathematical code cracking. QKarD, however, manages to achieve both the large quantity needed and true randomness by exploiting the inherently probabilistic nature of quantum particles such as photons (particles of light).

The quantum encryption platform currently requires that the sender and the recipient be linked via fiber optic cable to a central server to allow communication of the quantum keys with photons rather than ordinary electrical current. Therefore, the target market for the new QKarD product will likely be a single fiber optic-linked organization housed under one roof or within a contiguous campus. Future development of the QKaRD concept will focus on broader long-distance communication.

Ray Newell, a physicist on the Los Alamos QKarD team assisting in the technology transfer process with Whitewood, says the first commercial prototype system will be in operation later this year. Some of the initial marketing challenges will involve reducing production costs to be competitive in the current market and convincing potential buyers to invest in a fundamentally new method of encrypting their data. Yet if successful, QKarD will bring with it a much-needed, renewed confidence in information security, with high-throughput encryption that is unbreakable by any known or foreseeable cryptographic methods. Eventual applications include systems for banking, online transactions, secure facility access, electronic voting, and more.

—Owen Summerscales



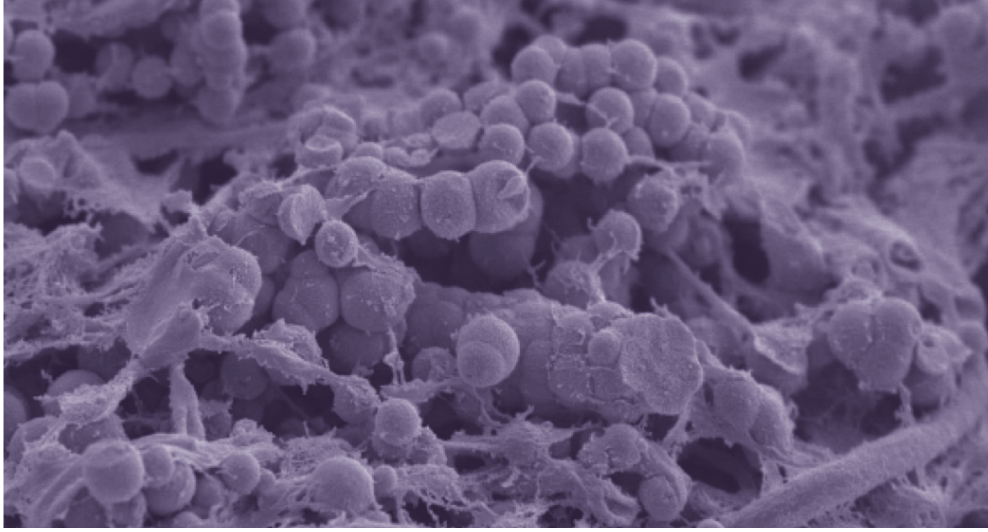
Slime-busting Salt

Many organisms in the natural world rely on each other and their surroundings for safety. Microorganisms, including bacteria and fungi, take this reliance one step further by sticking together—quite literally. They secrete proteins, DNA, and sugars to create a slimelike substance that helps them adhere to one another and to a surface. Together, the organisms and their slime are referred to as a biofilm.

Biofilms are great for microbes. They provide a secure environment in which the organisms are physically protected from dangers, such as antibiotics or drying out, while being able to communicate and network with each other by sending chemical signals. This ability to persist in various conditions allows biofilms to form anywhere—they comprise the slime lining on the inside of a glass fish tank or the plaque that accumulates on one's teeth.

Unfortunately for humans, when biofilms are made of nefarious organisms, they can be a significant problem. In fact, biofilm-protected bacteria account for about 80 percent of total bacterial infections in humans and are 50 to 1000 times more resistant to antibiotics than their free-floating counterparts. Specifically, it is difficult for antibiotics to penetrate biofilms to kill the bacteria inside. To make matters more complicated, bacteria in this protected environment can develop antibiotic resistance and even confer the resistance to other members of the biofilm community.

Much research over the years has been centered on trying to physically disrupt and destroy biofilms, but often the successful treatments (such as bleach or the removal of dead tissue) are quite toxic and painful to humans and therefore tend to be used as a last resort. Recent work by Los Alamos biochemist David Fox and his collaborators at the University of California, Santa Barbara, Dixie State University, and Northern Arizona University has shown that an innocuous substance, a molten salt called choline-geranate, can be used to physically disrupt biofilms as well as facilitate drug delivery. Specifically, this room-temperature liquid was found to completely eradicate the biofilm-forming pathogenic bacterium *Pseudomonas aeruginosa* in addition to physically penetrating the skin. The observation that the molten salts were able to both disrupt biofilms and kill disease-causing bacteria is a result with a lot of promise for therapeutics.



Biofilms are made of bacteria and secreted proteins, DNA, and sugars that together create a slimelike substance that helps them adhere to one another and to a surface. Los Alamos is working with collaborators on a way to disrupt problem-causing biofilms.

CREDIT: Jill Banfield, Department of Earth and Planetary Science, UC Berkeley

"Like a Trojan horse, we expected the salt to act as a carrier, delivering antibiotics to the bacteria inside the biofilm," says Fox. "The surprise was that the salt acted as an antimicrobial itself that was nontoxic to the other cells around." The molten salts were found to be at least as effective, if not more so, as bleach in breaking up the biofilm and killing the bacteria. But surprisingly, unlike bleach, there was no marked deleterious effect on a skin-wound model.

Molten salts are a type of ionic liquid—meaning they are made up of positively and negatively charged atoms. The exact mechanism by which they break down the biofilm is still being worked out; however, there are a couple of hypotheses. For one, it is thought that the ions interfere with the hydrogen bonding network that helps hold the biofilm matrix together. And when it comes to killing the bacteria themselves, Fox explains that it is possible the liquid also physically disrupts the cell membrane, bursting the cell or causing enough stress to the cell that it commits suicide. The mechanism by which the liquid seamlessly penetrates the skin, however, remains a mystery. Fox and his collaborators are hoping to find out more about the disruption mechanisms from a current trial using live mice in a collaborative effort with Andrew Koppisch and Nate Nieto at Northern Arizona University.

In tissue-culture experiments, choline-geranate was tested (in comparison to bleach) on established biofilms of *Salmonella enterica* and *Pseudomonas aeruginosa*. The salt increased delivery of the antibiotic cefadroxil by more than 16-fold into the deep tissue layers of the skin without inducing skin irritation. In the new trial, healthy mice will first be tested for inflammation or other adverse affects from the ionic liquid. If successful, mice infected with the flesh-eating bacteria, Methicillin-resistant *Staphylococcus aureus* (MRSA), will be given choline-geranate to determine its effectiveness.

If the studies continue to show success, this ionic liquid could be a promising treatment for skin infections. Since both molecular components of the molten salt are already generally recognized as safe by the by the Federal Drug Administration, it is reasonable to hope that this new compound would advance quickly through clinical trials.

Biofilms often persist in the periphery of a wound, beneath an intact, healthy skin layer. This makes them a major cause of chronic wounds and wound degradation. "What's exciting is that choline-geranate is able to penetrate through the skin and effectively carry antibiotics to the deepest layers," says Fox. Since bacterial infections in the skin are among the most common diagnoses in hospital patients, accounting for some 10 percent of all hospital visits, a new treatment that gets them deep in their hiding places may be just what the doctor ordered.

—*Rebecca McDonald*